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SPACE SHUTTLE AGING ELASTOMERS

Session: Space - Aging Orbiter

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Abstract

The reusable Manned Space Shuttle has been flying into Space and returning to earth for more than 25 years. The Space Shuttle's uses various types of elastomers and they play a vital role in mission success. The Orbiter has been in service well past its design life of 10 years or 100 missions. As part of the aging vehicle assessment one question under evaluation is how the elastomers are performing. This paper will outline a strategic assessment plan, how identified problems were resolved and the integration activities between subsystems and Aging Orbiter Working Group.

Introduction

The Aging Orbiter Working Group (AOWG) focus on elastomers was sharpened while performing pre-launch checkouts during a helium signature test in preparation for "return to flight" (RTF) with Space Shuttle Discovery (Orbiter Vehicle, OV-103) flight number 31. A leak was detected in the gaseous hydrogen flow control valve. The AOWG supported the failure analysis (FA) of this nitrile/Buna N o-ring and results pointed out the need to assess elastomer usage on the Orbiters. One of the most important configurations of the Orbiter is where interfaces come together in a mating condition. The majority of these interfaces contain metallic and non-metallic materials. A proper seal is mandatory to eliminate any leak paths and elastomers can play this vital role. Leak paths can also provide opportunities for moisture to initiate metallic corrosion problems. The AOWG defined elastomers as a polymer, which upon deformation and subsequent release of the deforming force, returns to approximately its original shape and dimensions. The term rubber is often used interchangeably with elastomer, though a rubber is compounded with an elastomeric polymer and various additives and curing agents, and is typically cured at some elevated temperature. The AOWG identified the following elastomer types used on Orbiters; Butyl (propellant, high vacuum and non oil resistant), Ethylene-propylene-diene-monomer (EPDM - hydrazine resistant), Neoprene (flame, weather and oil resistant or general purpose), Fluorocarbon (Viton, Kel-F and Kalrez – oil, solvent, fuel, corrosive industrial chemical, ultraviolet and ozone resistant), Silicone rubber (high temperature and ozone resistant) and Nitrile/Buna-N rubber (fuel and oil resistant). In addition, when investigating seal performance the polyurethane type revealed some problems that will be discussed. The Orbiter utilizes elastomers in the various configurations; valves (check, control and relief), regulators, electrical connectors, pressure switches, vibration buffers, air lock, hatch, doors, umbilicals, quick disconnects and pyrotechnics. Elastomeric materials can be beneficial with repair of metallic or non-metallic anomalies. The scope of elastomer usage can be valued by just assessing one simple material - nitrile rubber. There is approximately 1,900 individual component or detailed locations

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where nitrile rubber is used on the Orbiter. A good percentage of these parts are considered critical. The question that the AOWG formulated is – can degradation of nitrile rubber contribute to this subsystem's hardware not performing to designed requirements? The importance of assessing aging elastomers is increased since some lacked a defined shelf, age or usage life. The cost to resolve an elastomer failure outweighs the original procurement cost by several magnitudes. As future Space travel is extended to longer timelines understanding elastomer aging will become priceless. The Space Shuttle's hardware can provide the necessary aging knowledge resource to help define elastomer life limits and minimize impacts to future space explorations.

Results

The Orbiter contains three gaseous hydrogen (GH₂) flow control valves (FCV) that regulate pressure in support of the three main engines. During pre-launch helium leak checks it was determined that one of the three FCV's leaked helium. The analysis of leak rate directed that the Buna-N o-ring from the leaking FCV, identified as LV-58 for main engine #3 be removed and replaced. The high magnified inspection of removed o-ring identified radial cracks that could have provided leak paths across sealing surfaces.

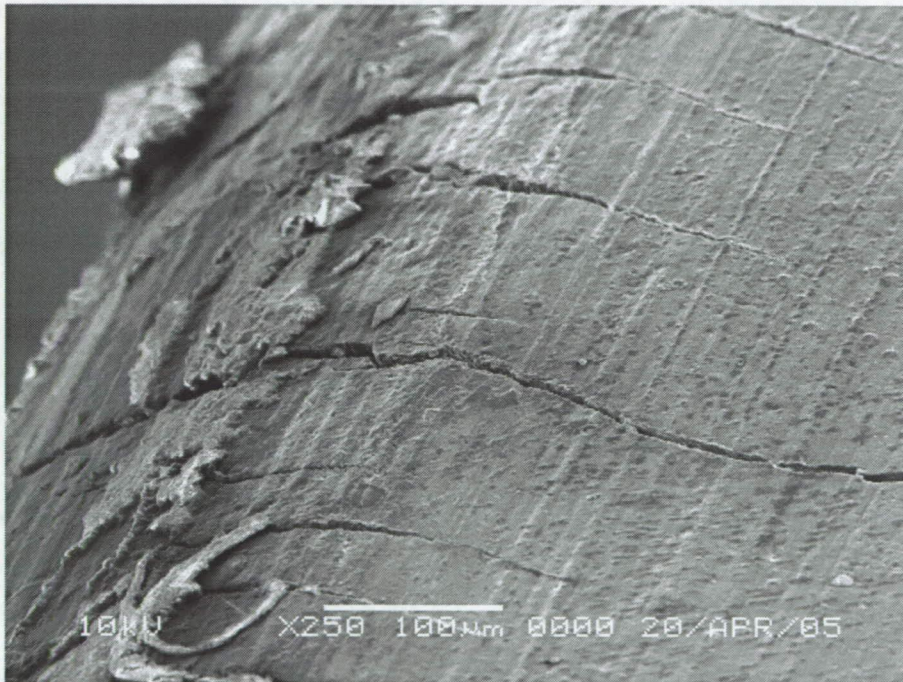


Figure 1: Radial cracks on failed o-ring

The remaining o-rings on the other two FCVs were also removed and replaced with new o-rings to insure no leakage and successful launch of Discovery. Atlantis and Endeavour had their FCV o-rings removed and replaced. FA investigation determined that 6 of the 9 o-rings from all three Orbiters contained cracks. The one that leaked and initiated the problem was the most severe. Additional FA work included laser dimensional, Shore A hardness and properties from a dynamic mechanical analyzer (DMA) and an Instron tensile machine. The FCV by design has a 9-mil (0.009 in.) gap that allows exposure of o-ring to ozone, air and elevated temperatures, accelerating the weathering process leading to cracking.

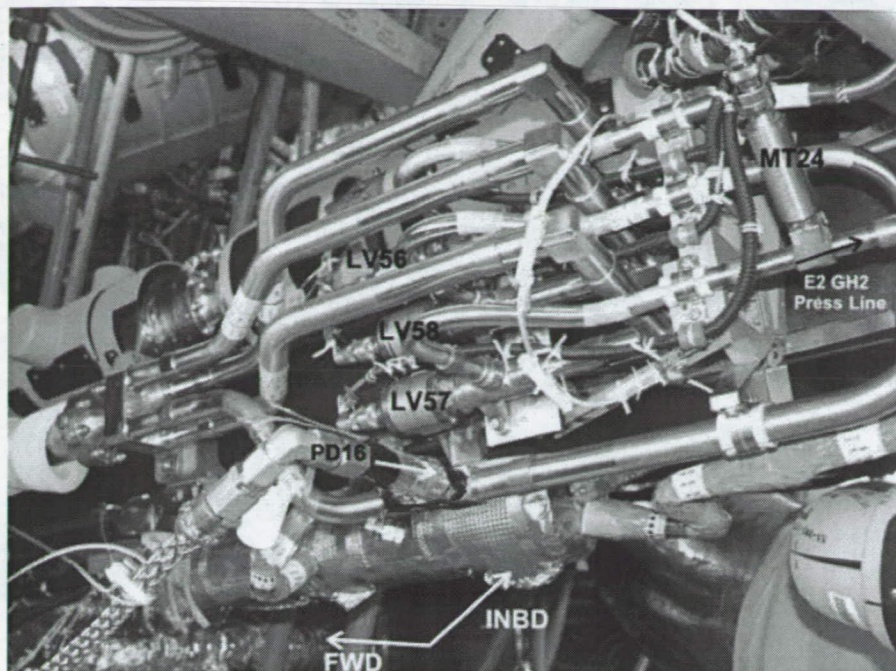


Figure 2: Installed GH2 Flow Control Valves

Additional o-rings were found in storage at both Marshall Space Flight Center and Kennedy Space Center of various ages. A reference curve was generated for DMA glass transition temperature (T_g) versus shelf life storage time ranging from 8 to 26 years. There was a difference noted for modulus and shore A hardness on the cracked o-ring that initiated the investigation.

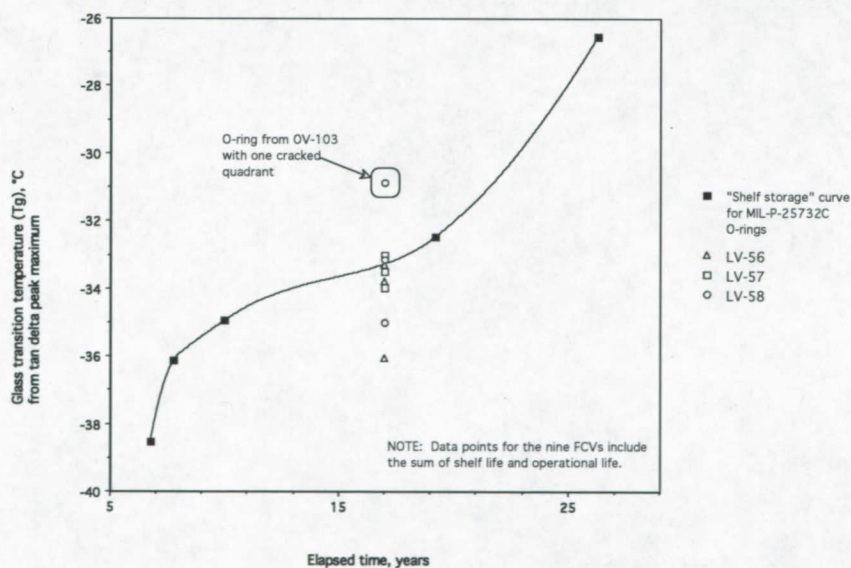


Figure 3: T_g versus age of used and unused Buna-N o-rings

The failed o-ring also had white frosting discoloration providing more evidence that the radial cracks could be attributed to ozone attack. These o-rings are exposed to dry purged air the majority of their post installed static environmental life. The purged air is provided with electrical motors and frequent lightning strikes increase the normal ozone levels.



Figure 4: Lightning strike at launch pad during normal thunderstorms

Many may confuse the effects of ozone and oxidation on rubber o-rings, but the two factors yield different results: (a) ozone attacks only the surface of the o-ring to cause rubber cracking, but oxidation causes a hardening that begins at the surface and progresses throughout the entire o-ring; (b) temperature has little effect on the rate of ozone attack, but in an oxidizing environment, each 10° C increase roughly doubles the rate of oxidation; (c) strain in the o-ring has no effect on oxidation reactions, but strain increases the rate of crack growth in the presence of ozone. During launch countdown and loading of cryogenic fluid the o-rings are exposed to cryogenic temperatures and 105° F on separate sides of sealing surfaces of o-ring. This environment provides strains and aging effects that are needed to degrade o-ring. A post installed operational life was implemented of 3 years to mitigate cracking concerns. These o-rings will be removed in the future from each Orbiter and tested to better understand aging effects.

Another Orbiter elastomer failure was in a regulator used in the fuel cell power reactant subsystem. Again the problem was detected during pressure decay leak checks failing quantity allowed over a specified amount of time. The FA identified that the valve stem's elastomer flashing material was inadequately trimmed during a manufacturing process and age hardening of material allowed a particle to interfere with the sealing surface. Further FA investigation the diaphragm also showed cracking potential and the original neoprene material was changed to more resistant EPDM for future configurations. The fuel cell

regulators and purge valves have also encountered problems with hardening of o-rings. A limited life requirement insures potential issues are managed.

The Orbiter's nose wheel steering actuator revealed low pressure hydraulic fluid threshold failures. The FA investigation identified an o-ring aging problem used in the pressure switch which allowed the diaphragm to experience out of tolerance readings. Even though Nitrile o-rings should survive many years when exposed continuously to hydraulic fluids there are some examples of failures. The inspection requirements prior to installation could be improved with high magnification and aided by light. The pre-existing condition of any o-ring can affect the operational age life.

The Orbiter uses elastomers in areas where off gassing and total mass loss (TML) are important requirements to eliminate contamination during on orbit vacuum exposures. There have been several cases where improper bake out was not performed prior to usage. These instances when found caused operational impacts to remove material and perform bake out procedures. Process control and properly communicating requirements to all persons involved in the process has been recognized as important corrective actions. The protection from Ultraviolet light exposure should be insured after elastomers are precision cleaned and repackaged in clean room materials.

The sabot seals used in parachute mortar assemblies are compounded with polyurethane material. They were found cracked, yellowing and embrittled prior to use but after installation. The storage conditions after installations and age may have contributed to dry rotting and degrading material to the point of where they could not be used. These seals were older than 10 years and are installed early in the build up of the mortar assembly. Shore A hardness readings indicated material did not meet requirements. Upon requesting new seals to be manufactured the material used previously was not available due to obsolescence. A new material was chosen and post installed storage conditions were improved with a controlled environment to minimize the aging process.

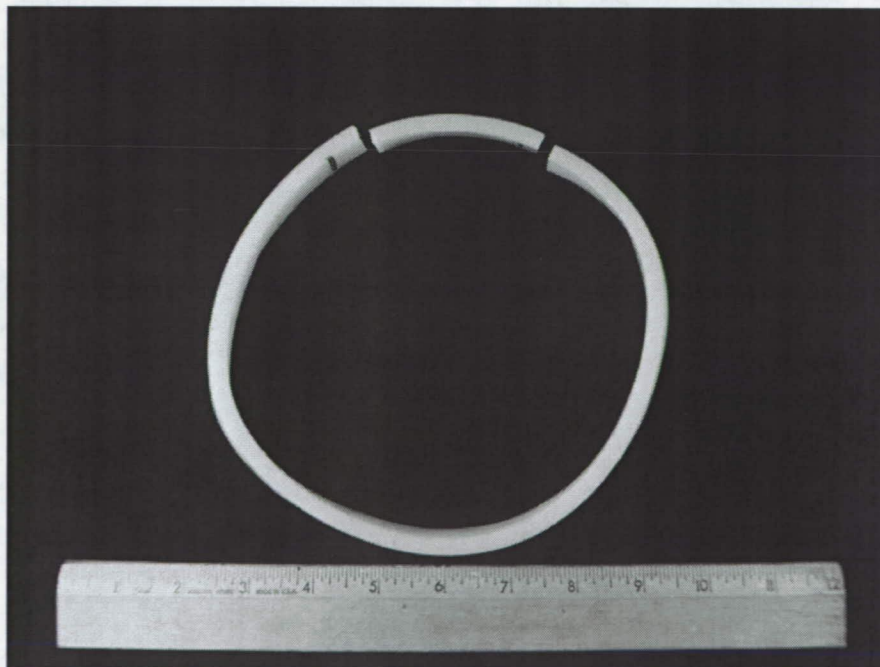


Figure 5: Failed polyurethane mortar assembly seal

Recently the AOWG recognized that historical information associated with each elastomer's post operational material property characteristic is not readily available. What are the real aging effects since no methods have been established for evaluating aged non problem components? Historically only problems have been evaluated and sometimes these low cost elastomers are just replaced during refurbishment at vendors with no FA performed. The Space Shuttle Program is transitioning hardware from various storage locations to a no not retain mode and opportunities to capture this information are being reduced. There have been instances where the AOWG recognizes hardware and request for this to be retained for further evaluation. Kennedy Space Center's facilities and equipment have also experienced elastomer failures with the age extending back into the 1960's vintage. As modifications proceed to upgrade for the next manned space program opportunities will arise to capture aged material data. There have been findings during refurbishment activities where 40 year old elastomers were staged for installation. Awareness communicated from AOWG to the technicians identified the need to capture aging data and these items were flagged. The AOWG has obtained these materials and will continue to test and evaluate properties in attempt to provide age trend data. Currently there is no funding to perform this assessment for either the Orbiter's or KSC equipment elastomeric materials.

Elastomeric material is used for beneficial repair methods of metallic and non-metallic materials. This material is monitored for property performance and doesn't provide a risk upon usage. The aging of this repair material is only monitored with inspections and if found to have a problem is removed and replaced. No aging studies to date have been performed on removed material.

The AOWG has a plan to evaluate Orbiter hardware and identify risks. They have identified all elastomer materials and their respective components of where they are installed. These parts are assessed for criticality and where used. Generic questions are formulated by the AOWG and forwarded to responsible subsystem personnel to address static and dynamic environments. This life cycle assessment of the elastomer can flag out aging concerns. Historical problems are then reviewed for trending. Inspection, acceptance, packaging, storage and supportability methods are evaluated. Although not fully implemented a plan to retrieve all elastomers upon refurbishment of a component at any original equipment manufacturer (OEM) or depot repair facility has been developed to support aging assessment. Opportunities to capture aging data on elastomers exist.

Conclusion

The Space Shuttle Orbiters contain thousands of elastomers located in hardware interfaces and components performing critical operations. The age of these elastomers can range from new to greater than 25 years. There have been elastomer failures and FA investigations indicate problems may have stemmed from original material to the environment that they are exposed to. Elastomers do age and become embrittled. The elastomer aging effects are known for some that have failed but not fully understood for ones that have been in operation with no failures. The design of elastomer usage is important and understanding each one's life cycle can point out potential problems. Elastomers are fairly inexpensive and should not be underestimated in their forgiving nature. Resolving elastomer problems are costly and can impact schedules when certification requirements of spares requires lengthy acceptance test and or special cleaning processes to return to print. Conservative approaches with elastomers will minimize problems. The Orbiter project is proceeding to understand elastomer aging effects and may require additional funding. Facilities and equipment elastomers are very similar to flight hardware and information from this venue may provide beneficial comparisons. Opportunities exist to collect, analyze and develop adequate aging characteristics. These opportunities could be shared with industry and

academia to improve effectiveness of hardware and efficiency of operations during turnaround activities. More stringent requirements can insure elastomers don't reduce risk.

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10th Joint DoD/NASA/FAA Conference on Aging Aircraft

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Cris Curtis

April 16-19, 2007

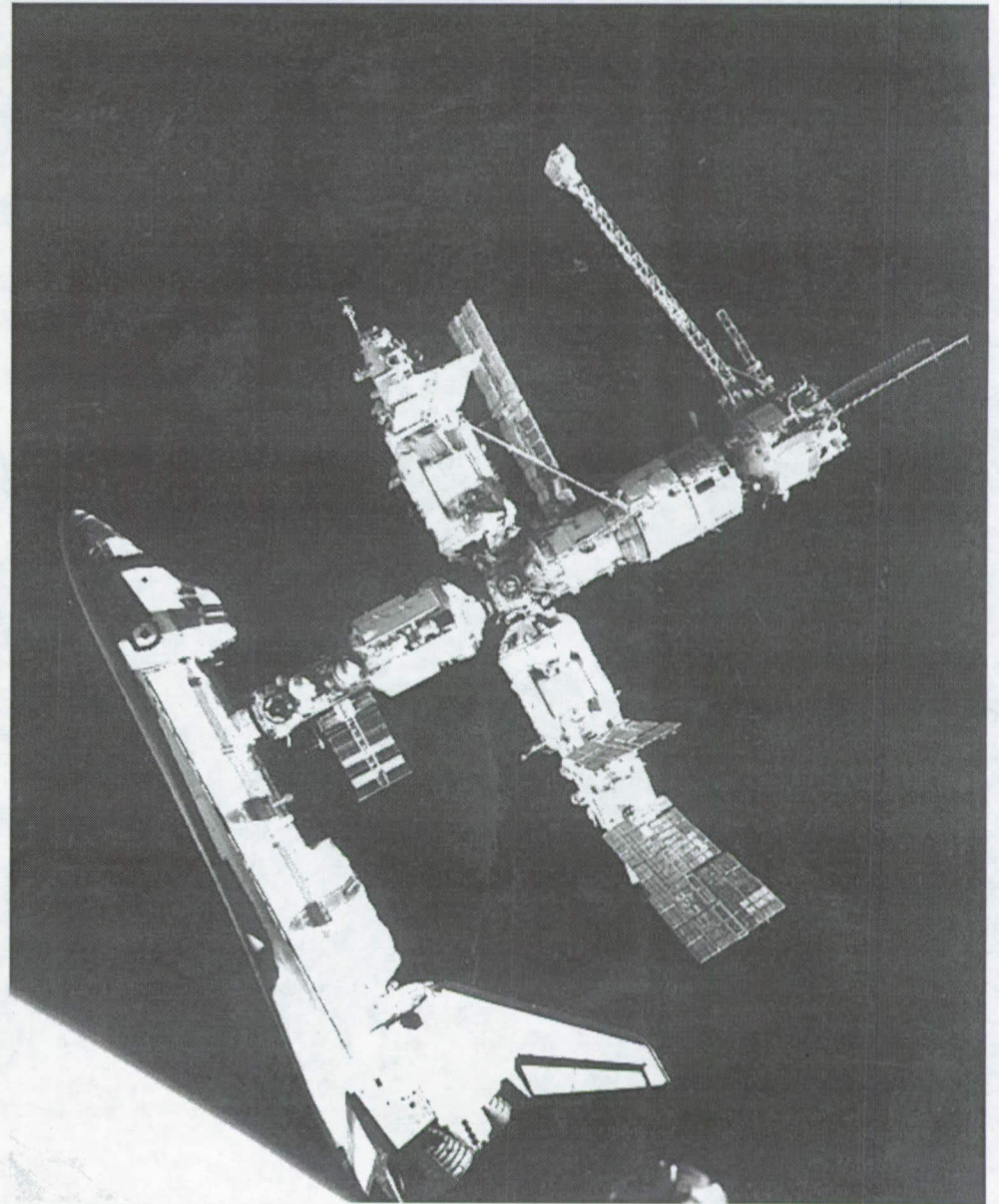
Agenda

- Introduction
- Investigation
- Discussion
- Conclusions



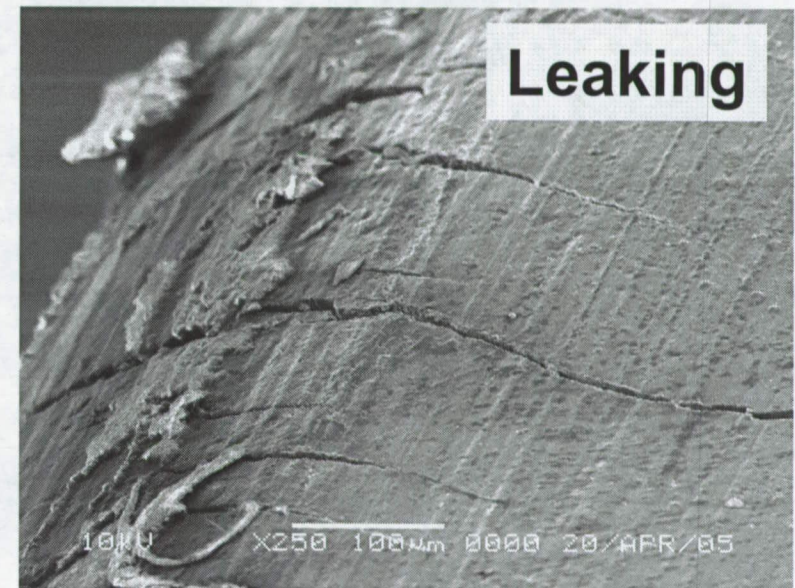
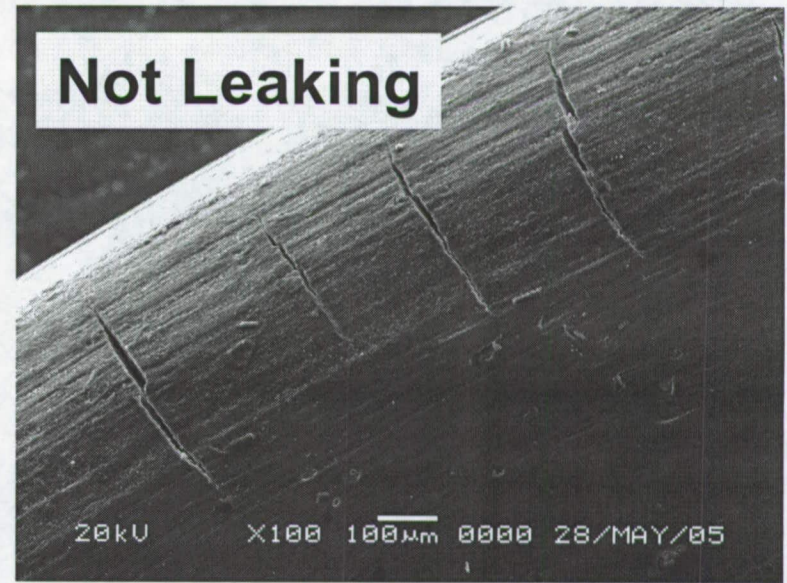
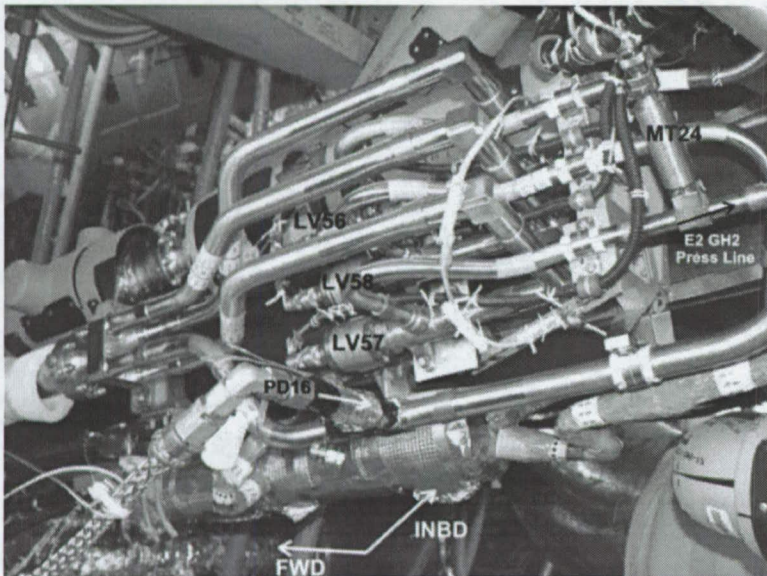
Introduction

- **Elastomers**
 - **Aging Orbiter Working Group**
 - **Definition**
 - **Types**
 - **Purpose**
 - **Where used**
 - **Problems**
 - **Opportunities**



Investigation

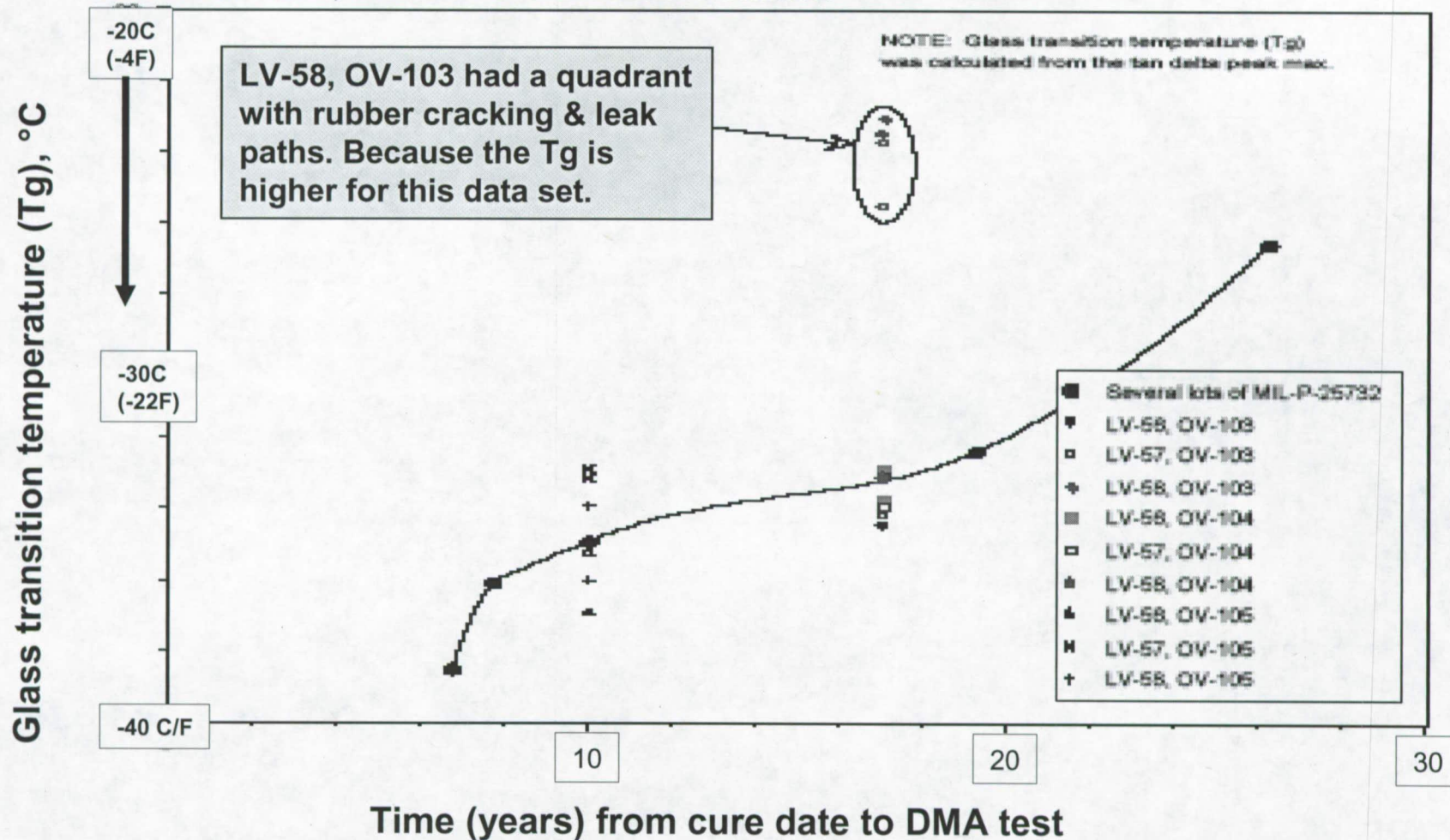
- **Discovery's Return to Flight**
 - **Main Propulsion System, Gaseous Hydrogen Flow Control Valve O-Ring Leak**
- **All Orbiter's O-rings replaced**



Investigation

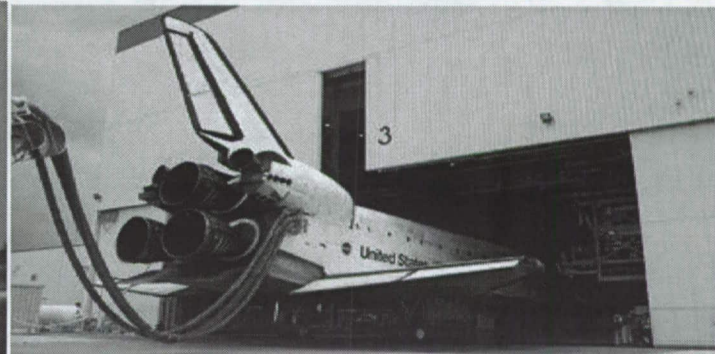
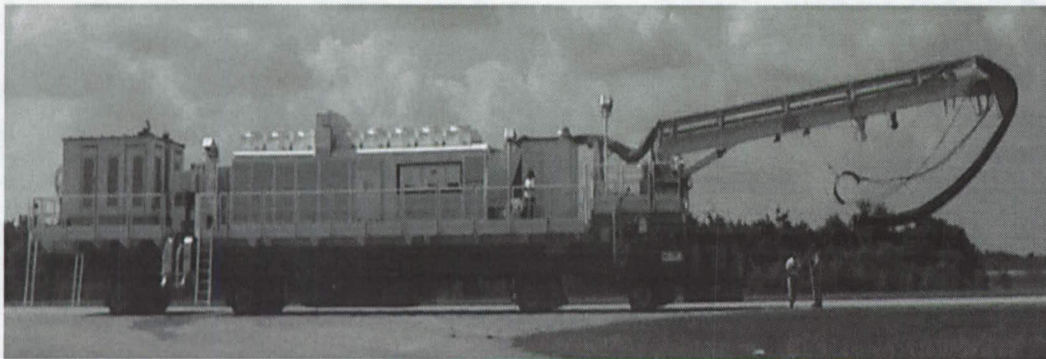
- Failure Analysis of FCV O-ring

Dynamic Mechanical Analysis (DMA) glass transition temperature (T_g) for MIL-P-25732 nitrile o-rings: several cure dates, and for 3 FCVs on each of 3 Orbiters.



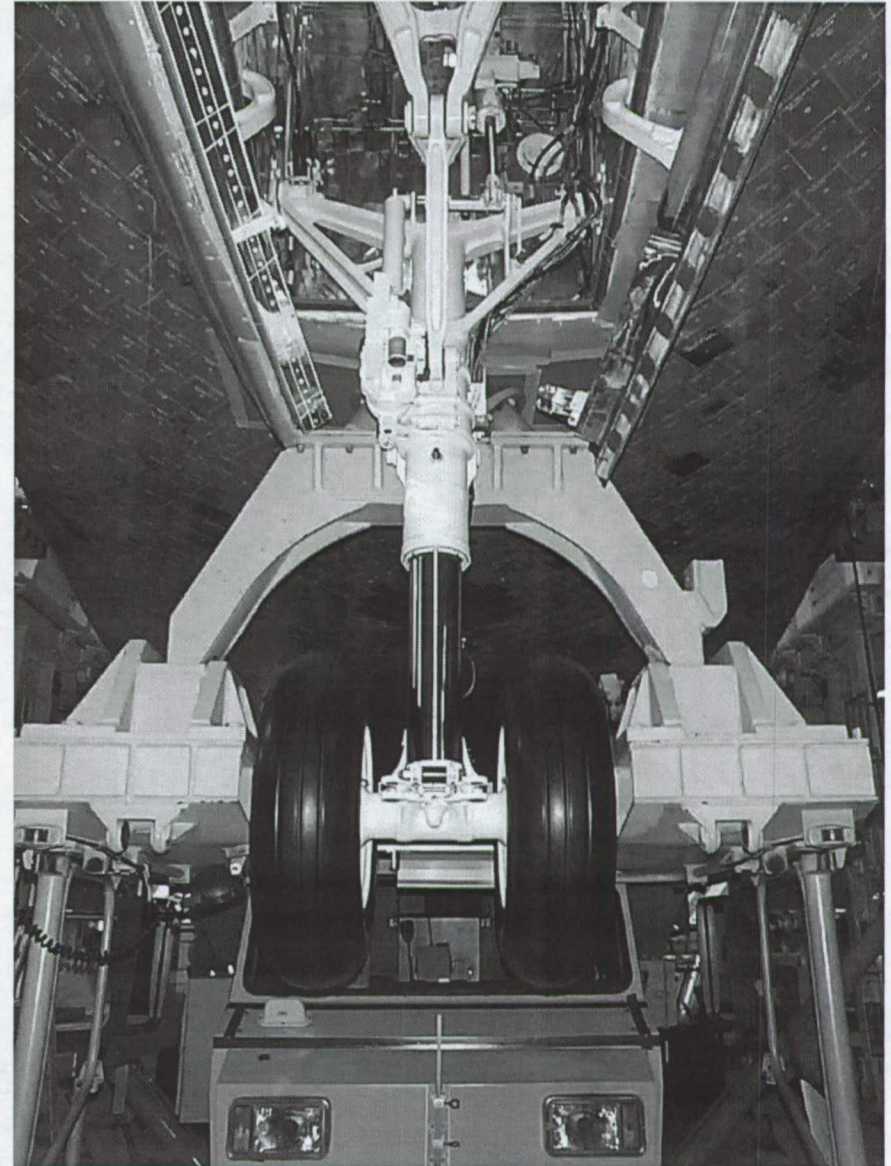
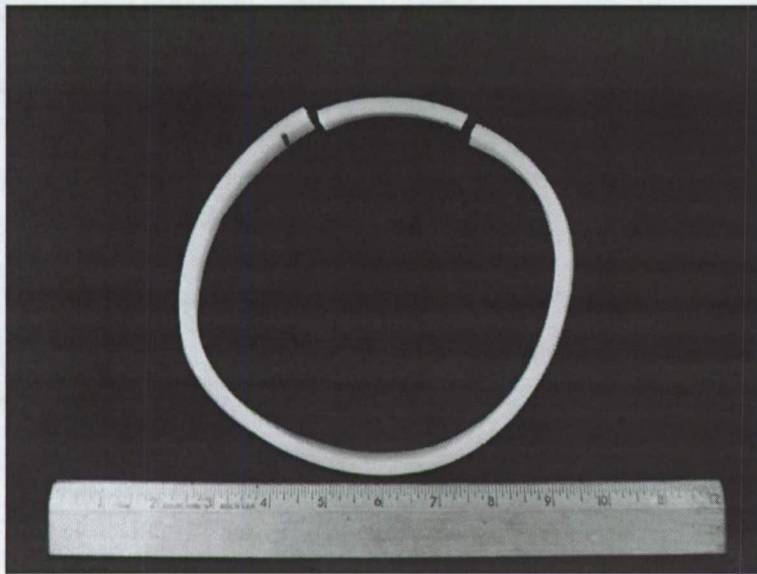
Investigation

- FCV O-Ring Environment
 - Temperature
 - Pressure
 - Air
 - Ozone
 - Electromagnetic



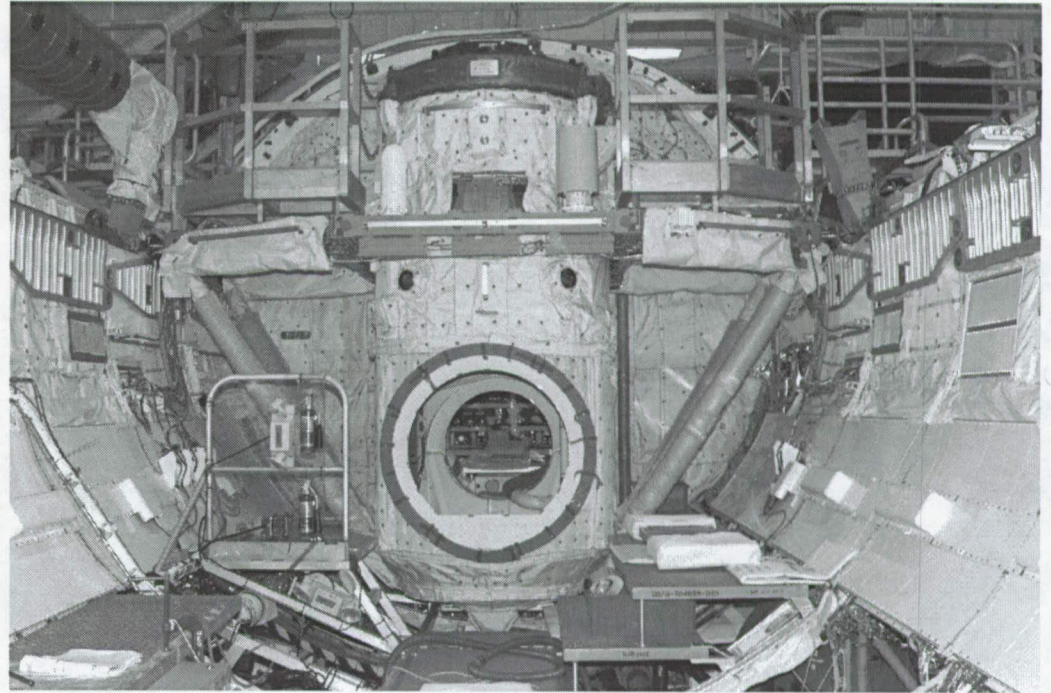
Investigation

- Regulators
- Diaphragms
- Pressure Switches
- Actuators
- Pyrotechnics



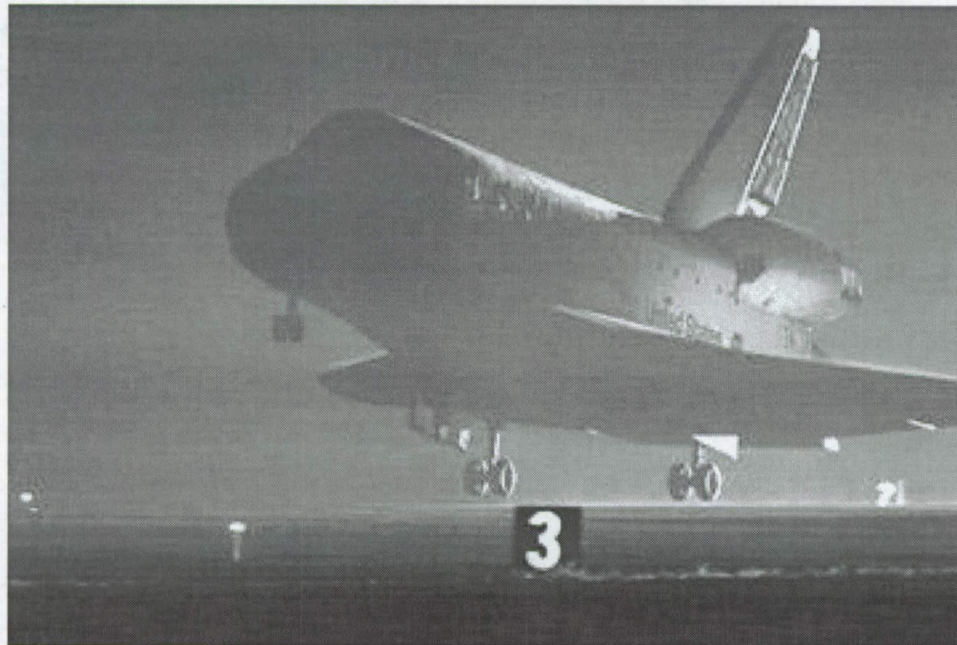
Discussion

- **Usage**
 - Interfaces
 - Valves
 - Doors
 - Quick Disconnects
- **Vacuum Stability**
- **Refurbishment**
- **Opportunities**
 - Constellation
 - Long Term Exposure



Conclusions

- **Mission Success**
 - Managing aging elastomers is important
 - Requirements and process control must be satisfied
 - Environment affects aging process
 - Rework or repair of elastomers impacts cost and schedule
 - Elastomers contribute and play vital role



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1. REPORT DATE (DD-MM-YYYY) 03-28-2007		2. REPORT TYPE		3. DATES COVERED (From - To) 04/16/2007 - 04/19/2007		
4. TITLE AND SUBTITLE Space Shuttle Aging Elestomers				5a. CONTRACT NUMBER NA59-20000		
6. AUTHOR(S) CRIS CURTIS				5b. GRANT NUMBER		
				5c. PROGRAM ELEMENT NUMBER		
				5d. PROJECT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) United Space Alliance - Orbiter Element USK-167 8550 Astronaut Blvd. Cape Canaveral, FL 32920-4304				5e. TASK NUMBER		
				5f. WORK UNIT NUMBER		
				8. PERFORMING ORGANIZATION REPORT NUMBER Orbiter Element		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) NASA - M47 CRichard Russell Kennedy Space Center, FL. 32899				10. SPONSOR/MONITOR'S ACRONYM(S)		
12. DISTRIBUTION/AVAILABILITY STATEMENT				11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
				13. SUPPLEMENTARY NOTES		
14. ABSTRACT Provides Plan to assess how the Orbiter's Aging Elestomers are performing past Design Life.						
15. SUBJECT TERMS						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT		18. NUMBER OF PAGES	
a. REPORT	b. ABSTRACT	c. THIS PAGE			19a. NAME OF RESPONSIBLE PERSON CRIS CURTIS	
					19b. TELEPHONE NUMBER (Include area code) 321. 861. 8278	